BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: AAP-1/AAP-2 Configuration Data for Solar Orientation Implementation Studies - Case 600-3

DATE: August 7, 1967

FROM: P. G. Smith

ABSTRACT

Data are given for use in several AAP-1/AAP-2 solar orientation implementation studies now in progress. The data presented are: dimensions, mass, location of the mass center and center of pressure, moments and products of inertia, principal moments of inertia, relations between the principal and geometrical axes, and the aerodynamic torque coefficient. These are given for each of three spacecraft configurations, namely, those for which the CSM is docked on ports 3, 4, and 5 of the Multiple Docking Adapter.

In connection with this work, a digital computer program was written to obtain the inertia properties of a composite body.

(NASA-CR-154781) AAP-1/AAP-2 CONFIGURATION DATA FOR SOLAR ORIENTATION IMPLEMENTATION STUDIES - CASE 600-3 (Bellcomm, Inc.) 12 p

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MEMORANDUM FOR FILE

1. INTRODUCTION

This work was prompted by the desire to use a current, common set of configuration data in each of several studies dealing with alternative schemes for maintaining the AAP-1/AAP-2 spacecraft in a fixed orientation relative to the sun. The data required may generally be thought of as dimensions, inertia properties, and quantities which allow the computation of the aerodynamic torque acting on the vehicle.

An effort has been made to present those data which reflect the current spacecraft design, and insofar as is possible, the assumptions made and sources of information consulted are given.

2. CONFIGURATIONS CONSIDERED

The vehicle under consideration comprises an S-IVB Orbital Workshop, its associated solar panel array, an Airlock Module and Multiple Docking Adapter (AM/MDA), and a Command and Service Module (CSM). Three distinctly different spacecraft configurations are obtainable by docking the CSM on different ports of the MDA; for this study the CSM is docked on port 3 (opposite port 1), port 4, and port 5 (axial port), the latter being illustrated in Figure 1.

3. METHOD OF COMPUTATION

3.1 Inertia Properties

Mass, mass center location, and moments and products of inertia are obtained by updating the data of Reference 1 in the following manner:

1. The Mapping and Survey System (M&SS) Module is

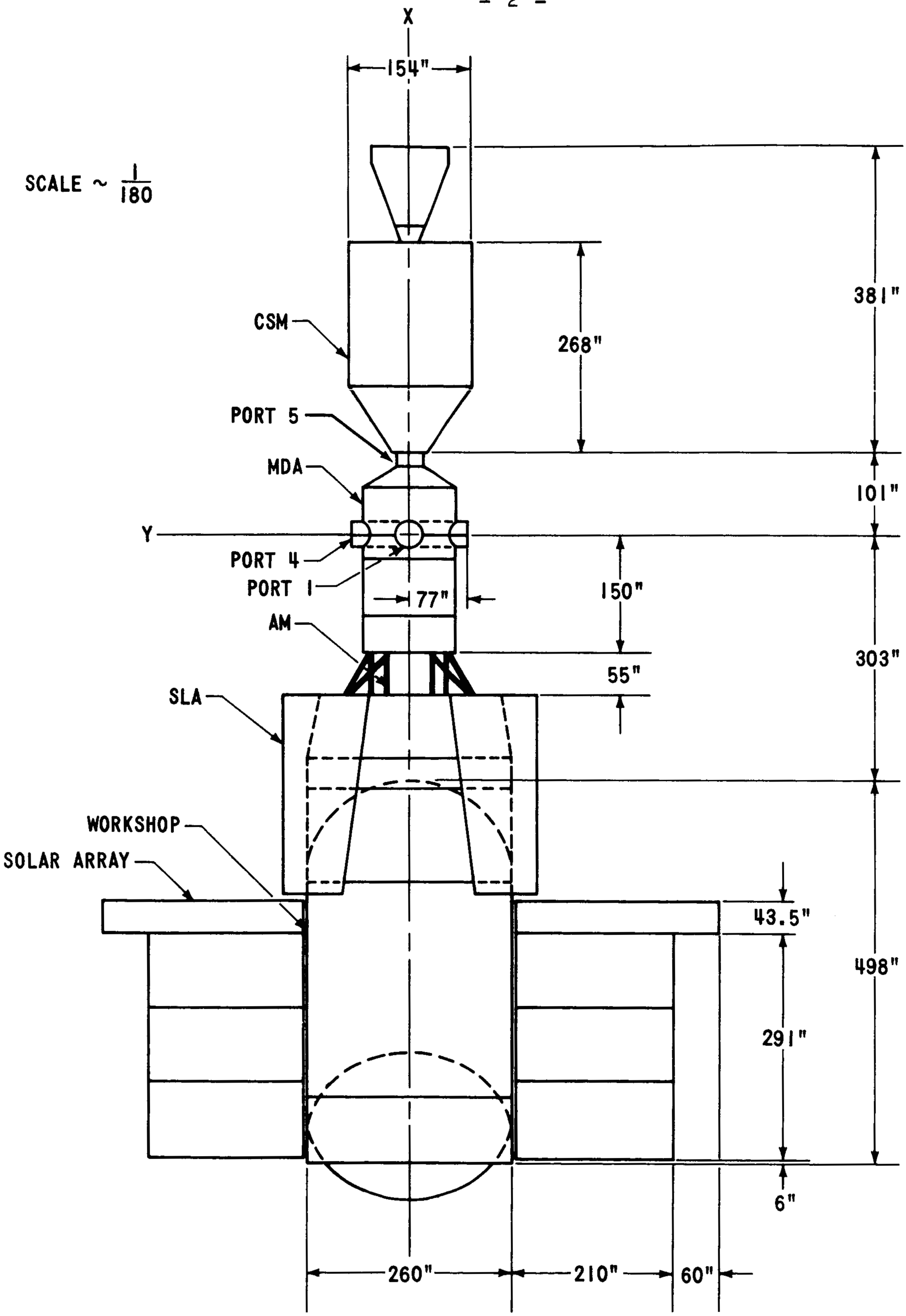

FIGURE 1 - AAP-1/AAP-2 IN THE PORT 5 CONFIGURATION

removed. Inertia properties of the M&SS are obtained by "subtracting" Case 2 from Case 5 of Reference 1.*

2. The latest available information (Reference 2) indicates that the AM has lost 4600 pounds since Reference 1 was published, while the Service Module (SM) has gained 5200 pounds and the Command Module (CM) has gained 2100 pounds. The updating is effected by considering these weight changes to be concentrated at the mass centers of the appropriate modules.

3.2 Aerodynamic Loads

In a simple model of the aerodynamic effects, considered to be satisfactory for the analyses being undertaken, it is assumed that the force produced is parallel to the vehicle velocity vector and that this force acts at a point fixed in the vehicle, called the center of pressure. For a given wind direction, the location of the center of pressure may be computed from data given in Reference 3 for the Port 4 Configuration; these data are also sufficient to allow the computation of the center of pressure location for the other two configurations. In the computations, the wind is taken to be directed normal to the solar array.

The magnitude of the aerodynamic torque depends on atmospheric density, a quantity which varies widely due to changes in orbital parameters and solar activity. Two values of density, obtained from Reference 4, are presented: ρ_1 is the average over one orbit of the nominal density prediction, whereas ρ_2 is the average over one orbit of the maximum density. Both vales are for a 248 n.mi. circular orbit during a period of maximum solar activity (November, 1968).

$$\rho_1 = 6.2 \times 10^{-15} \text{ slug ft.}^{-3}$$

$$\rho_2 = 2.5 \times 10^{-14} \text{ slug ft.}^{-3}$$

*See Appendix.

The location of the center of pressure relative to the mass center is, together with the direction of the velocity vector, sufficient for the determination of the direction of the aerodynamic torque vector. The magnitude of this vector, rather than being given explicitly, is expressed as α, the ratio of the maximum aerodynamic torque to the maximum gravity-gradient torque:

$$\alpha = \left[\frac{rC_D A\rho V^2}{2}\right] \Big/ \left[\frac{3}{2}\Omega^2 (I_{max} - I_{min})\right]$$

where r is the distance from the mass center to the center of pressure, C_D is the coefficient of drag, A is a reference area, V is the vehicle velocity, Ω is the orbital rate, and I_{max} and I_{min} are the maximum and minimum moments of inertia of the spacecraft for its mass center.

4. RESULTS

Data are presented in terms of the right-hand xyz coordinate system shown in Figure 1, and the following definitions apply:

w: Vehicle weight in pounds.

α_1, α_2: Torque ratios corresponding to ρ_1 and ρ_2.

X_{mc}: Mass center location in inches.

X_{cp}: Location of the center of pressure in inches.

I: Inertia tensor for the mass center in slug ft^2.

I_1, I_2, I_3: Principal moments of inertia for the mass center in slug ft^2.

T: Transformation from the principal (1,2,3) axes to the geometrical (x,y,z) axes; each column of T contains the direction cosines of the x,y, and z axes for the principal axis associated with the moment of inertia given at the head of the column.

θ: Angles between the principal and geometrical axes in degrees; $\theta_{ij} = \cos^{-1} t_{ij}$, i = 1,2,3, j = 1,2,3.

4.1 Dimensions

Pertinent dimensions are given in the figure. As these are obtained from a number of sources, it is not possible to cite a reference for them.

4.2 Port 3 Configuration

$$w = 81{,}812 \qquad \alpha_1 = .05 \qquad \alpha_2 = .21$$

$$X_{mc} = \begin{bmatrix} -281.4 \\ -3.2 \\ -86.6 \end{bmatrix} \qquad X_{cp} = \begin{bmatrix} -514 \\ 0 \\ -27 \end{bmatrix}$$

$$I = \begin{bmatrix} 3.88 \times 10^5 & 1.45 \times 10^4 & 4.48 \times 10^5 \\ & 2.08 \times 10^6 & -5.49 \times 10^3 \\ & & 1.88 \times 10^6 \end{bmatrix}$$

$$I_1, I_2, I_3 = 2.63 \times 10^5 \quad 2.08 \times 10^6 \quad 2.00 \times 10^6$$

$$T = \begin{bmatrix} .964 & .003 & .268 \\ -.008 & 1.000 & .018 \\ -.267 & -.020 & .963 \end{bmatrix}$$

$$\theta = \begin{bmatrix} 15.5 & 89.8 & 74.5 \\ 90.5 & 1.1 & 89.0 \\ 105.5 & 91.1 & 15.6 \end{bmatrix}$$

4.3 Port 4 Configuration

$w = 81{,}812 \qquad \alpha_1 = .04 \qquad \alpha_2 = .18$

$$X_{mc} = \begin{bmatrix} -281.4 \\ 88.9 \\ 1.4 \end{bmatrix} \qquad X_{cp} = \begin{bmatrix} -458 \\ 27 \\ 0 \end{bmatrix}$$

$$I = \begin{bmatrix} 3.81 \times 10^5 & -4.43 \times 10^5 & 1.10 \times 10^4 \\ & 1.86 \times 10^6 & 7.63 \times 10^3 \\ & & 2.09 \times 10^6 \end{bmatrix}$$

$$I_1, I_2, I_3 = \quad 2.59 \times 10^5 \qquad 1.98 \times 10^6 \qquad 2.09 \times 10^6$$

$$T = \begin{bmatrix} .964 & -.267 & -.004 \\ .267 & .963 & .040 \\ -.007 & -.040 & .999 \end{bmatrix}$$

$$\Theta = \begin{bmatrix} 15.4 & 105.5 & 90.2 \\ 74.5 & 15.6 & 87.7 \\ 90.4 & 92.3 & 2.3 \end{bmatrix}$$

4.4 Port 5 Configuration

$w = 81{,}812$ $\alpha_1 = .04$ $\alpha_2 = .15$

$$X_{mc} = \begin{bmatrix} -181.4 \\ -1.1 \\ 1.4 \end{bmatrix} \qquad X_{cp} = \begin{bmatrix} -418 \\ 0 \\ 0 \end{bmatrix}$$

$$I = \begin{bmatrix} 1.51 \times 10^5 & 2.68 \times 10^3 & 2.25 \times 10^4 \\ & 3.13 \times 10^6 & -2.34 \times 10^3 \\ & & 3.13 \times 10^6 \end{bmatrix}$$

$$I_1, I_2, I_3 = 1.51 \times 10^5 \quad 3.13 \times 10^6 \quad 3.13 \times 10^6$$

$$T = \begin{bmatrix} 1.000 & .004 & .006 \\ -.001 & .904 & -.428 \\ -.008 & .428 & .904 \end{bmatrix}$$

$$\Theta = \begin{bmatrix} .4 & 89.8 & 89.6 \\ 90.1 & 25.4 & 115.4 \\ 90.4 & 64.6 & 25.4 \end{bmatrix}$$

5. APPENDIX: INERTIA PROPERTIES PROGRAM

In order to determine the inertia properties of composite bodies such as those for which data are presented in this memorandum, it is necessary to "add" the inertia properties of certain bodies and to "subtract" the inertia properties of others. For example, data for the Port 4 Configuration are obtained from Case 7 of Reference 1 by adding the properites associated with the weight increase in the CSM and by subtracting the properties of the M&SS and those associated with the loss of weight in the AM. This appendix describes a general Fortran program that performs this task.

In a given rectangular coordinate system, let m_i be the mass and X_i (3 x 1 matrix) the mass center location of body i, i = 1, · · ·, n, the total number of bodies to be considered; also let I_i' (3 x 3) be the inertia tensor of body i for its mass center in some convenient rectangular coordinate system for body i, T_i' (3 x 3) being the transformation from this body coordinate system to the given system. If body i is to be "added" to the composite body, m_i is taken to be positive, and if it is to be "subtracted", m_i is assigned a negative value.

Now, by making use of the quantities defined in Section 4*, we have

$$m = \sum_{i=1}^{n} m_i$$

$$X_{mc} = \frac{1}{m} \sum_{i=1}^{n} m_i X_i$$

*The composite mass m replaces w. Also, a consistent system of units must be used throughout.

$$\begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} = X_i - X_{mc}$$

$$r_i^{\,2} = x_i^{\,2} + y_i^{\,2} + z_i^{\,2}$$

$$I = \sum_{i=1}^{n} \left\{ \mathrm{sgn}(m_i) T_i' I_i' T_i'^{T} + m_i r_i^{\,2} E \right.$$

$$\left. -m_i \begin{bmatrix} x_i^{\,2} & x_i y_i & x_i z_i \\ x_i y_i & y_i^{\,2} & y_i z_i \\ x_i z_i & y_i z_i & z_i^{\,2} \end{bmatrix} \right\}$$

where sgn (x) has the value +1 when x is positive, zero when x vanishes, and -1 when x is negative, and where $T_i'^{T}$ is the transpose of T_i' and E is the 3 x 3 identity matrix. I_1, I_2, I_3 are simply the eigenvalues of I, and the columns of T are the normalized (to unit length) eigenvectors of I.

Values for $|m_i|$, X_i, T_i', and I_i', as well as a 24 character alphanumeric name, are read into the computer for each body to be used in the study. The manner by which these bodies are to be combined to form the composite body is controlled by another set of input quantities C_i, C_i assuming the value +1 if body i is to be added to the composite body, -1 if it is to be subtracted from the composite body, and 0 if body i is to be ignored. In addition to the computations described in the previous paragraph, the computer program provides for rearranging the eigenvalues and eigenvectors so as to have the off-diagonal elements of T as small as possible. Then the eigenvectors are further normalized so that the diagonal elements of T are positive. Output values include the input data for all bodies not ignored, as well as all inertia properties presented in Section 4.

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